

A cool R Coronae Borealis star Z UMi

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Abstract. The high resolution spectra of a R CrB type star Z UMi are analysed. The atmospheric parameters of Z UMi are estimated $T_{\text{eff}} = 5250 \pm 250$ K and $\log g = 0.5 \pm 0.3$. This places Z UMi among the coolest R CrB stars. The hydrogen deficiency of Z UMi is confirmed. The abundances of other elements resemble those found for the minority group of R CrB stars. We note very low iron abundance, $[\text{Fe}/\text{H}] = -1.85$, and an excess of lithium, $[\text{Li}/\text{Fe}] = +1.9$.

Key words: stars: atmospheres – stars: individual: Z UMi

1. INTRODUCTION

Z UMi (an optical counterpart of an IR-source IRAS 15060 + 8315) was classified as a R Coronae Borealis star by Benson et al. (1994). Before that Z UMi was thought to be a Mira variable with a possible period of 450 or 500 days (Kholopov et al. 1985). The classification as a R CrB star relied on the photometric and low resolution spectroscopic observations. The photometry showed characteristic to R CrB stars light drop by 6 magnitudes in 1992, which lasted about 300 days. Low resolution spectra obtained during the light minimum showed only the Na I D lines in emission and the C₂ Swan system bands in absorption. No Balmer lines were detected.

The hydrogen-deficient nature of Z UMi was established by Goswami et al. (1997), who used the high resolution ($R \approx 60\,000$) spectra of the star during maximum light. The CN red and violet systems and the C₂ Swan system bands were found in absorption. Weak or absent CH bands in Z UMi spectra were considered as the indicators of hydrogen deficiency. The high resolution ($R \approx 30\,000$) spectrum of

ZUMi during the onset of the 1997 decline was studied by Goswami et al. (1999).

In this paper we present the high resolution spectra of ZUMi during its maximum light.

2. OBSERVATIONS

Our high resolution spectra were obtained with the Nasmyth Echelle Spectrometer (Panchuk et al. 1999; Panchuk et al. 2002) of Russian 6 m telescope on March 10, 2004 (JD 2453075), when the star was at maximum light ($V \approx 11.3$). The spectrograph was equipped with an image slicer (Panchuk et al. 2003). As a detector a CCD camera with 2052×2052 pixels produced by the Copenhagen University Observatory was used.

The spectra cover 528–677 nm without gaps until 586 nm. The spectra were reduced using the NOAO astronomical data analysis facility IRAF. The continuum was placed by fitting low order spline functions through the manually indicated points in every order. The use of image slicer results in three parallel strips of spectra in each order. These strips are wavelength shifted. Therefore all strips were reduced separately and then already linearized in the wavelength spectra were coadded. We checked the accuracy of this procedure (Kipper & Klochkova 2005) and found that the wavelengths of the terrestrial lines in the stellar spectrum were reproduced within a few 0.001 Å-s. After that all spectra of the set were coadded.

As measured from the Th-Ar comparison spectra the resolution is $R \approx 42\,800$ with FWHM of comparison lines about $7\,\text{km s}^{-1}$.

3. DESCRIPTION OF THE SPECTRA

3.1. Atmospheric parameters

No multicolor photometry is available for ZUMi. Goswami et al. (1997) compared the high resolution spectra of ZUMi at maximum light with the spectra of carbon star UU Aur (N3, C5,4) and the R1 spectral type hydrogen-deficient (HdC) star HD 182040. They found that the C_2 Swan bands in ZUMi spectrum were much stronger than in HD 182040 indicating a lower temperature. At the same time ZUMi is not as cool as UU Aur. In Figures 1 and 2 our spectra of ZUMi and HD 182040 are compared in two C_2 band-head regions. Our spectra also show much stronger C_2 bands in the ZUMi spectrum. Asplund et al. (1997) estimated for HD 182040 $T_{\text{eff}}=5600\,\text{K}$.

This estimate took into account a correction to the photometric temperature $T_{eff} = -500$ K to reach better agreement with the spectroscopically obtained values of other RCrB type stars. Tenenbaum et al. (2005) have analyzed CO band observations in RCrB stars and accepted $T_{eff} \approx 5000$ K for ZUMi on the basis of CO band visibility. With the temperature close to 5000 K, the mean $M_{bol} = -5 \pm 1$ and the mass $\mathcal{M}/\mathcal{M}_{\odot} = 0.7 \pm 0.2$ of RCrB stars (Asplund et al. 2000), the surface gravity will be close to $\log g = 0.5 \pm 0.3$. Tenenbaum et al. (2005) found that there is very little difference in the strengths of CO absorption bands if $\log g = 0.5$ or 1.5. The current spectra are not suitable for the spectroscopic determination of the microturbulence parameter ξ_t . We choose the value $\xi_t = 5$ km/s close to the mean value of cooler RCrB stars. One of the parameters necessary in constructing the atmospheric models of hydrogen-deficient stars is the C/He abundance ratio as He is likely the most abundant element and C I is thought to be the main agent of the continuous opacity. Therefore, the element abundances from line intensities represent actually the element-to-carbon abundance ratio (Asplund et al. 2000). The C/He ratio for cool RCrB stars cannot be determined observationally. For hotter RCrB stars and EHe stars Pandey et al. (2001) found C/He ratio (by number) close to 0.01. We choose this value for ZUMi too. The input abundances of other elements are those adopted by Asplund et al. (1997) for the RCrB stars.

3.2. Model atmospheres

The model atmospheres for this analysis were computed with a modified version of MARCS program (Gustafsson et al. 1975) with updated opacities. The opacities from continuum sources, molecules CO, CN, C₂, HCN, C₂H₂ and C₃, and the metallic lines were taken into account. The line opacities were treated in opacity sampling approximation (Jørgensen et al. 1992). The structure of these models fits well with the Uppsala line blanketed models described by Asplund et al. (1997), when models with the same parameters are compared. We started with the model 5000/0.5 (C/He=0.01). Synthesizing the spectral region with the C₂ Swan system (0,1) band head we found that the computed C₂ rotational lines were too strong. Raising the effective temperature to $T_{eff} = 5250$ K does not completely remove the discrepancy. Still higher T_{eff} seems to be unacceptable due to the temperature limit set by Tenenbaum et al. (2005) concerning the visibility of CO bands. The quite slight reduction of the input carbon abundance to $\log \varepsilon(C) = -2.2$ gives an acceptable fit. Therefore the fur-

ther analysis was performed with the model 5250/0.5 (C/He=0.006). We estimate the error in T_{eff} about 250 K.

3.3. Elemental abundances

Z UMi shows in its spectrum many strong C₂ Swan system bands including the (3,6) and (1,4) bandheads at 658.9 and 676.2 nm which are usually not visible in early-type R carbon stars. The lines of these bands are naturally not included into the Bell (1976) list, which is the main used line-list. We synthesized these bands using the line-list generated at the Indiana University (Alexander 1991). About the spectral line-lists for carbon stars see Kipper (2004). If these two red bands were taken into account, the mean carbon abundance of Z UMi is $\log \varepsilon(\text{C}) = -2.04 \pm 0.20$. Without these bands $\log \varepsilon(\text{C}) = -2.10 \pm 0.1$. This means that for C₂ molecular spectrum there is no so-called carbon problem (Asplund et al. 2000). For CI lines the problem is present at the level of about -0.5dex as for all other R CrB type stars analyzed up to now. After fixing the input carbon abundance at the level of -2.10 , the following nitrogen abundance was found fitting CN rotational lines: $\log \varepsilon(\text{N}) = -3.0 \pm 0.2$, which almost coincides with the mean nitrogen abundance $\log \varepsilon(\text{N}) = -3.1 \pm 0.5$ for 20 R CrB stars analyzed by Asplund et al. (2000).

Determining the abundances from individual spectral lines is extremely ambiguous in the case of Z UMi. There are no lines belonging to atomic species, which are not blended with molecular lines, and therefore no equivalent widths could be measured and the procedures like determining the microturbulence parameter ξ_t , adjusting T_{eff} using abundance versus excitation potential and $\log g$ determination using ionization equilibrium, are not applicable. Synthesizing the spectra only the upper limit of abundances could be found. As the lines, which could be used in this case are strong, the errors due to the errors in the structure of model atmosphere could not be estimated. Also, the error in the accepted microturbulence parameter t of about 1 km/s translates directly into abundance errors greater than $\pm 0.3\text{dex}$. This should be kept in mind when using the following abundance data. The oscillator strengths of used metallic lines in Bell's line-list were replaced with the solar ones by Thevenin (1989, 1990). The found abundances are listed in Table 1. The indicated errors reflect only the scatter due to use of different lines. The number of used lines, which is very small in most cases, is also indicated in the column Remarks. We found that the hydrogen abundance could not exceed 10^{-5} by synthesizing the H α line blend with CN lines. A few (5) lines of NI show

that $\log \varepsilon(N) \geq -3.1$. This is in accord with the N abundance found from CN bands. The oxygen abundance from 7 O I lines including [O I] lines at 630.02 and 636.39 nm is $\log \varepsilon(O) = -3.45 \pm 0.30$. The iron abundance from Fe I and Fe II lines $\log \varepsilon(Fe) = -5.9 \pm 0.3$ is very low. The almost coinciding abundances from Fe I (-5.93) and Fe II (-5.87) indicates that the combination of T_{eff} and $\log g$ is not too far from the reality. As was found earlier by Goswami et al. (1997), we note that the Li I line at 670.78 nm is clearly present and we estimate $\log \varepsilon(Li) \approx 3.3$ and $[Li/Fe] = 1.9$. This means that Z UMi is indeed the “Li-rich” R CrB star.

3.4. RADIAL VELOCITY

An important task for R CrB stars is a search for variability in their radial velocity. Based on few relatively unblended metallic lines, we determined an average value of radial velocity for the moment of star’s observation JD 2453074.6: $V_{rad} = -35.4 \pm 1.6$ km/s. From the rotational lines of C₂ (0,1) band we found -35.4 ± 1.8 km/s and (0,2) band -35.8 ± 2.0 km/s. Therefore we estimate the mean heliocentric radial velocity of Z UMi, $V_{rad} = -35.5 \pm 1.7$ km/s. Goswami et al. (1999) estimated $V_{rad} = -35 \pm 2$ km/s from the narrow emission lines in the decline spectrum of Z UMi. The photospheric velocity found by Goswami et al. (1997) is $V_{rad} = -37 \pm 2$ km/s. Taking into account the stated errors there are no changes in the radial velocity. The Gaussian decomposition of the Na I D-lines reveals three components presented in Table 2.

Two redmost and relatively sharp components could be of interstellar origin. The strongest and bluest component shows the presence of earlier expelled material expanding with the velocity of about 10 km/s. The larger blue extension and therefore the larger blueshift of the D₂ line compared to the D₁ line could be caused by a heap of C₂ and CN lines around 588.8 nm.

4. CONCLUSIONS

We found that Z UMi is one of the coolest R CrB stars with its $T_{eff} \approx 5250$ K. The other cool R CrB stars S Aps, WX CrA and U Aqr have $T_{eff} \approx 5000$ K. The even cooler DY Per ($T_{eff} = 3500 \div 4700$ K) is a prototype of a small group with very slow and much more symmetrical declines than the declines of R CrB stars (Alcock et al. 2001). It is not yet clear whether the DY Per stars are related to the R CrB stars. The derived abundances are very crude estimates. In spite of that we conclude that the chemical composition of Z UMi resembles

that of the minority group R CrB stars. Similarly to V CrA, VZ Sgr and V3795 Sgr it is very metal-poor. Nitrogen is overabundant as in the majority group and V CrA from the minority group.

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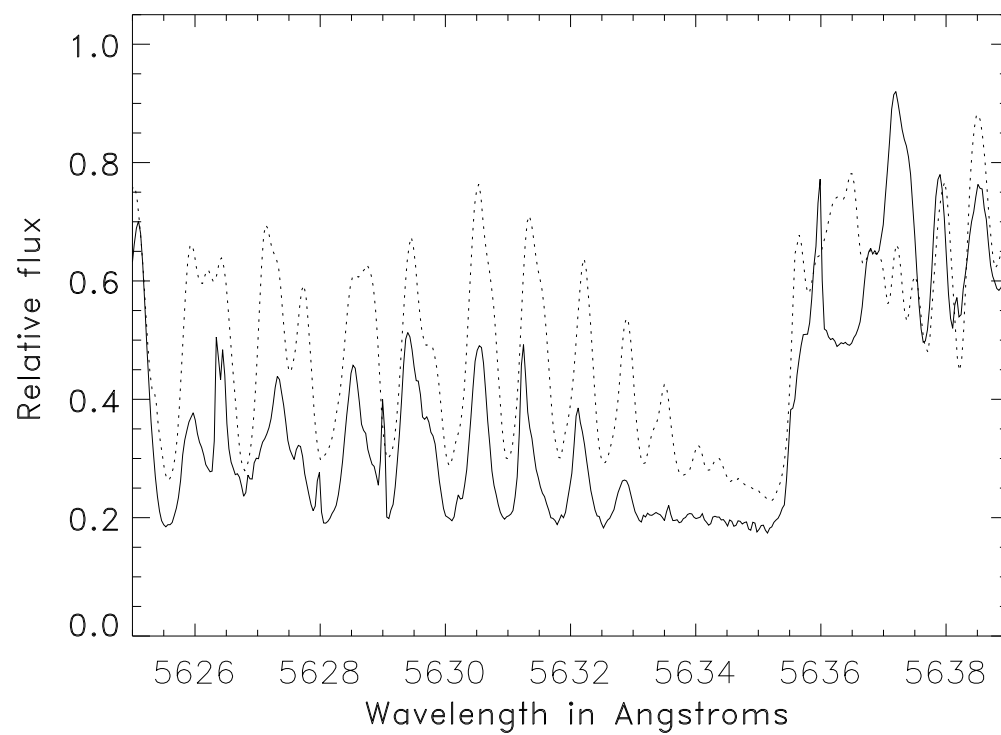


Fig. 1. Comparison of the spectra of Z UMi (full line) and HD 182040 (dotted line) near the C₂ (0,1) 563.550 nm bandhead.

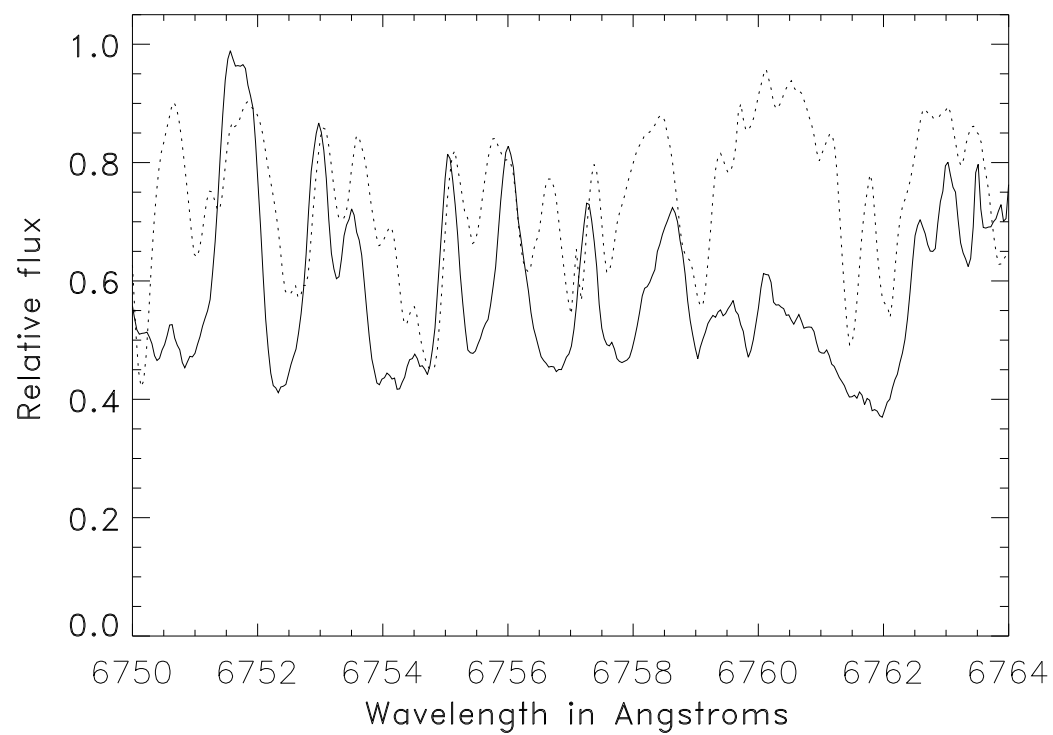


Fig. 2. Comparison of the spectra of Z UMi (full line) and HD 182040 (dotted line) near the C₂ (1,4) 676.195 nm bandhead.

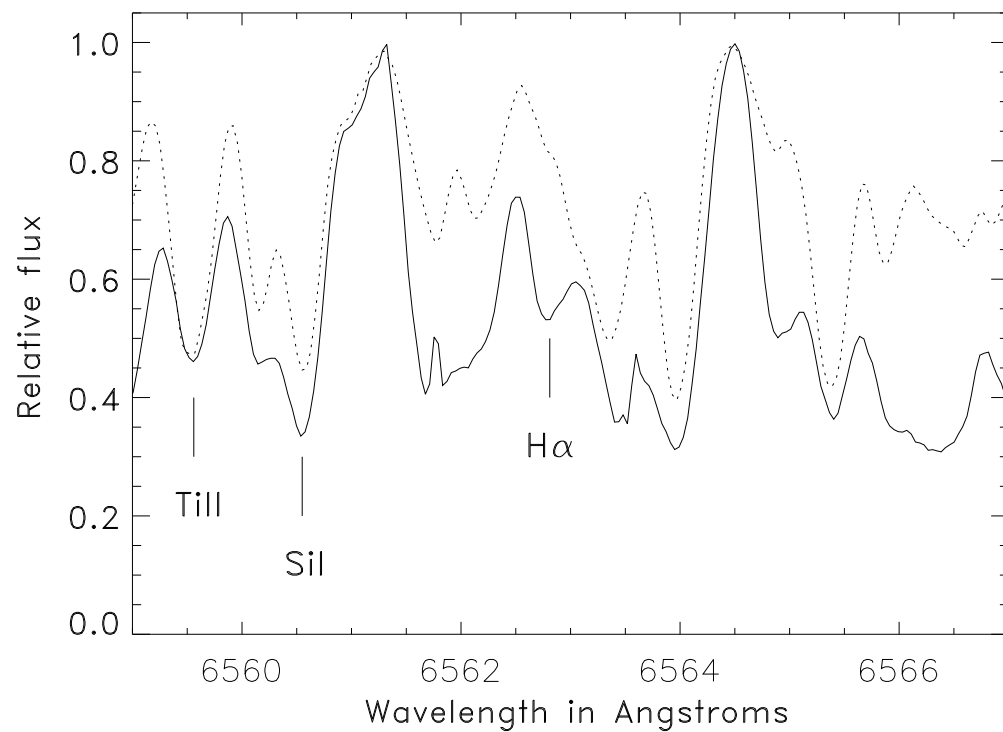


Fig. 3. Comparison of the spectra of Z UMi (full line) and HD 182040 (dotted line) near the H α line. The lines of Ti II and Si I are also indicated. All other lines belong to CN.

Table 1. Chemical composition of Z UMi, of the majority and minority groups of R CrB stars (Asplund et al. 2000), and the Sun (normalized to $\log \Sigma \mu_i A_i = 12.15$). The [El/Fe] spread in R CrB stars is given in parentheses.

El.	$\log \varepsilon$ Sun ¹	$\log \varepsilon$ Z UMi	Z UMi	[El/Fe] R CrB maj.	R CrB min.	Remarks
H	12.00	$\leq 10^{-5}$				
Li	3.25 ²	3.3	1.9	-0.1(0.8)	0.0(0.5)	
C	8.39	9.5 ± 0.2				C ₂ bands
N	7.78	8.4 ± 0.5	2.5	1.7(0.3)	1.9(0.7)	CN bands
O	8.66	8.1 ± 0.3	1.3	0.6(0.6)	1.5(0.6)	7 ³ O I and [O I]
Na	6.17	4.5	0.2	1.0(0.3)	1.6(0.2)	1 Na I
Mg	7.53	5.9	0.2	0.1(0.3)	-0.2(0.3)	1 Mg I
Al	6.37	5.8	1.3	0.6(0.3)	0.9(0.2)	2 Al I
Si	7.51	6.5 ± 0.5	0.8	0.6(0.3)	1.6(0.3)	8 Si I
Ca	6.31	3.9 ± 0.4	-0.9	0.3(0.2)	0.2(0.2)	3 Ca I
Sc	3.05	1.5 ± 0.5	0.3	0.7(0.6)	1.5(0.1)	9 Sc II
Ti	4.90	4.2 ± 0.2	1.2	0.1(0.4)	0.5(1.0)	6 Ti I
		3.2	0.2			2 Ti II
Cr	5.64	4.0 ± 0.3	0.2			7 Cr II
Fe	7.45	5.6 ± 0.3				77 Fe I
						20 Fe II
Co	4.92	4.2 ± 0.3	1.1			4 Co I
Ni	6.25	4.9 ± 0.3	0.5	0.6(0.2)	1.1(0.3)	4 Ni I
Y	2.24	0.8	0.4	0.8(0.6)	1.2(0.8)	1 Y II
Ba	2.17	0.0	-0.3	0.3(0.4)	0.6(0.2)	1 Ba II
La	1.13	0.3	1.0	1.3(0.5)	1.1(0.1)	2 La II

¹ Asplund et al. (2005), relative to $\log \varepsilon(\text{H})$,

² Meteoritic value,

³ Number of used lines.

Table 2. The Gaussian decomposition of the Na I D-lines in the spectrum of Z UMi. The equivalent widths and FWHMs are given in angstroms.

No.	$V_{\text{rad}}(\text{D}_2)$	$V_{\text{rad}}(\text{D}_1)$	$W_{\lambda}(\text{D}_2)$	$W_{\lambda}(\text{D}_1)$	FWHM(D ₂)	FWHM(D ₁)
1	-47.0	-43.8	0.69	0.48	0.83	0.57
2	-32.3	-33.0	0.07	0.10	0.30	0.25
3	-6.7	-7.9	0.35	0.32	0.41	0.37